Coral Reef Sanctuaries for Trochus Shells

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Introduction

Economically, the coral reef snail *Trochus niloticus* (Fig. 1) is the most important gastropod mollusk in the tropical Indo-West Pacific (Heslinga and Hillmann, 1981; Heslinga, 1981a). Commercial trochus fisheries exist in New Caledonia, Indonesia, Papua New Guinea, Australia, Vanuatu, Fiji, French Polynesia, the Philippines, and in the Marshall, Mariana, Caroline, and Solomon Islands (Wells, 1981a). Subsistence fisheries for trochus shells and meat exist in many other island areas.

The meat is edible and is dried, cooked, or occasionally canned for local consumption. The aragonite shells, primary raw material for mother-of-pearl buttons, are exported to Asia and Europe. The annual world harvest is about 5,000 t (Heslinga and Hillmann, 1981) with a dockside value of about $4 million (at $0.88/kg, Palau's 1982 price). The retail value of the finished product is many times higher, since an individual trochus shell worth $0.15 ex-vessel will make 35 buttons worth about $0.30 each at retail (Udui and Van den Andel, 1981).

Contrary to popular opinion, the widespread use of plastic buttons and other fastening devices has not depressed the world trochus market. Annual demand has been estimated at 6,000 t worldwide (Bouchet and Bour, 1980), and the dockside price of trochus shell has increased 500 percent during the last decade (Heslinga and Hillmann, 1981). The Pacific Island trochus industry remains a principal source of foreign exchange for artisanal fishermen, particularly in

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ABSTRACT—Trochus niloticus *is exploited throughout the tropical Indo-West Pacific as a source of food and mother-of-pearl. In the Republic of Palau, trochus sanctuaries were established in 1960 to serve as centers of breeding and planktonic larval distribution. However, 1982 field surveys indicated that Koror State sanctuaries averaged only half as many trochus as adjacent exploited areas. In addition, sanctuaries were too numerous and widely scattered to be effectively patrolled. Recommendations to consolidate and relocate the sanctuaries in superior trochus habitats were approved and implemented by Koror State officials before the 1982 trochus season opened.*

We conclude that marine sanctuaries can contribute to trochus conservation efforts and are of potential economic benefit if properly sited and patrolled. Guidelines are suggested for sanctuary selection and assessment of trochus distribution and abundance. Population densities are shown to be influenced by reef orientation, degree of exposure to surf, substrate type, and water depth.

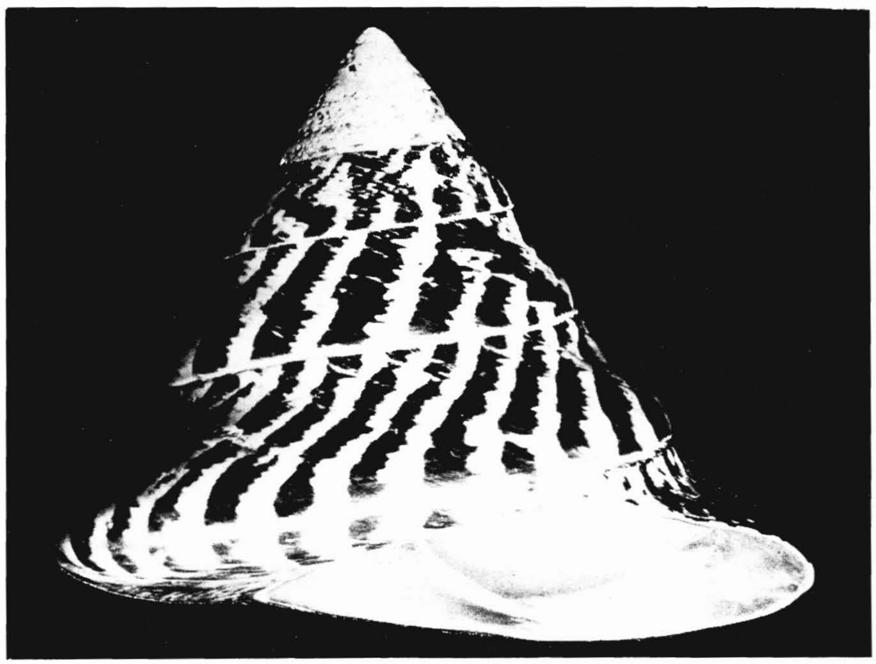

Figure 1.—Adult commercial topshell, *Trochus niloticus*, 10.2 cm base diameter.

remote areas. According to Glucksman and Lindholm (1982), who studied the commercial shell industry of Papua New Guinea:

"The importance of the shell trade to the coastal villager or to the nation cannot be measured solely in terms of cash earnings or Gross National Product. It is an industry ideally suited to coastal villages in that: The harvest of the shell does not require investment in expensive equipment or vessels; the reefs on which it is found are often contiguous with small population centres (a villager need not leave home to enter the cash economy); the saleable product requires no preservation and is easily packed and stored; and the meat (foot) of the snail is easily processed (salted and/or smoked) to provide a source of locally produced and preserved high quality protein."

Trochus depletion through unregulated or poorly regulated harvesting is of increasing concern in the Indo-West Pacific. Heslinga and Hillmann (1981) cite many cases where local stocks have been fished nearly to economic extinction, often in spite of regulatory measures. And, the International Union for the Conservation of Nature has recently added *T. niloticus* to its list of "commercially threatened invertebrates" (IUCN, In press).

Factors contributing to such declines include the large size, accessible habitat, and sedentary habit of *T. niloticus*. Complicating factors include a suite of problems commonly associated with resource management in developing countries. Examination of trochus management in the Republic of Palau, and documentation of a successful review and policy change in this paper is therefore both timely and relevant.

Since 1960, Palau's trochus management policy has included four components: 1) Size limit (7.6 cm base diameter); 2) restricted season (1 month/year, usually June); 3) a sanctuary system to protect designated areas; and 4) a moratorium system in which states or villages voluntarily stop collecting shells for one or more years. The moratorium system was invoked by Kyangle State in 1979, Angaur and Ngeremlengui States in 1980, and Koror, Kyangle, and Peleliu States in 1983.

The size limit and the seasonal restriction were originally implemented in the 1920's and 1930's during the Japanese occupation of Palau (Gail and Devambez, 1958). The sanctuary system was established under the American administration following a 2.5-year investigation by McGowan (1956, 1958, 1959).

McGowan (1956, 1958) presented data to support his position that "there has been a constant decline in the size of the catch from almost all of the trochus producing areas of the Pacific." He maintained that these declines occurred despite existing regulations on harvest and size. As for the decline in trochus harvests reported at various times from New Caledonia, the Philippines, the Andaman Islands, Yap, and Palau, McGowan (1959) concluded that "without a doubt, overfishing was the cause for these population declines, thus implying that the existing conservation practices were ineffective."

A trochus sanctuary system proposed by McGowan (1958), and later implemented in Palau, Truk, Ponape, and Yap, was based on the assumption that the protected areas would serve as spawning centers from which planktonic larvae would be distributed by currents up and down the reef. Although the early life history stages of *T. niloticus* had not been described during McGowan's studies, he hypothesized that trochus larvae must spend a short time in the plankton (days, as opposed to weeks or months) before settlement and metamorphosis (McGowan, 1958). Subsequent studies (Heslinga, 1981a,b; Heslinga and Hillmann, 1981) have corroborated McGowan's thesis.

T. niloticus larvae are now known to be of the short term lecithotropic type which, under favorable conditions, spend only a few days in the plankton. There is a high probability that trochus larvae which recruit successfully to the benthic environment do so within a few days drift of their point of origin. From a practical standpoint, this means that larvae produced in trochus sanctuaries probably do help populate nearby reefs. One would not necessarily expect the same to be true for gastropods with long-term planktotrophic larvae. In retrospect, the trochus sanctuary concept appears to have had a sound biological basis, in addition to obvious intuitive appeal.

At the outset of Palau's trochus sanctuary program, McGowan (1958) recommended establishing one sanctuary per 5 miles of barrier reef. This was evidently an arbitrary decision. It was stressed that to be effective, the sanctuaries must be "well made," i.e., placed in appropriate habitats for *Trochus niloticus*, and they must be patrolled regularly during the harvest season to discourage poaching. Subsequently, trochus sanctuaries were established in Palau by members of the local Conservation Division.[1] In Koror, the most populous state and the largest in terms of barrier reef perimeter, seven trochus sanctuaries were designated: Five on the east coast and two on the west coast (Fig. 2, 3).

At the request of the Palau Marine Resources Division, and with financial support from the Pacific Fisheries Development Foundation, we studied the original seven Koror State trochus sanctuaries in March-April 1982 to see if they were fulfilling their intended function. Underwater surveys provided a quantitative assessment of the distribution and abundance of harvestable trochus in sanctuary areas and in adjacent exploited areas. Another goal was to train Palauan Marine Resources Division personnel (Orak and Ngiramengior) to conduct and interpret quantitative field assessments of local trochus populations. The sampling techniques, methods of data analysis, and report format used for the Koror State trochus survey thus represent an attempt to

[1]Madraisau, B. 1981. Micronesian Mariculture Demonstration Center, Koror, Palau. Pers. commun.

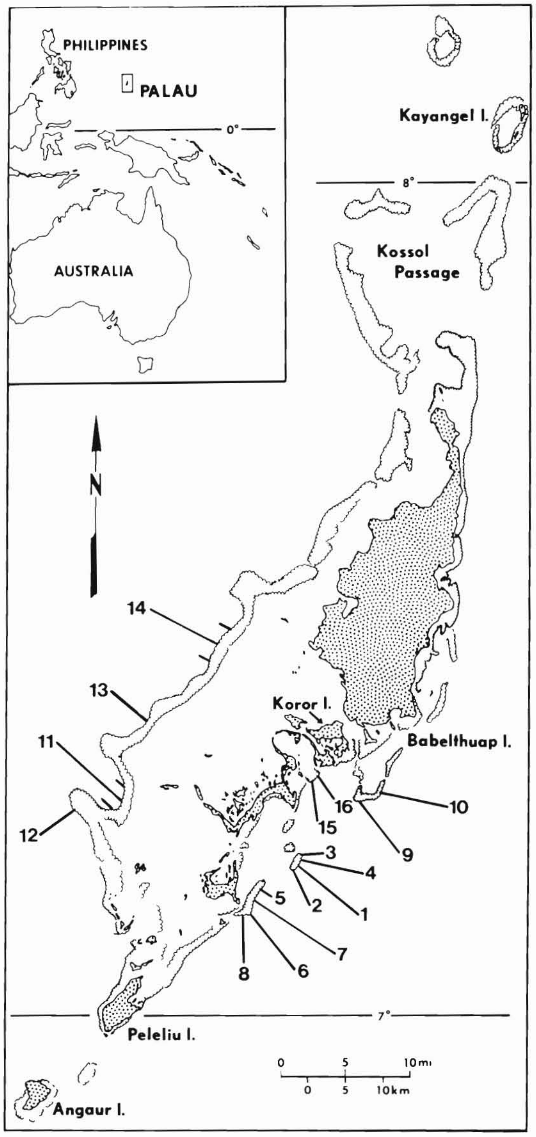

Figure 2.—The Palau archipelago, showing the 16 sites on the Koror State barrier reef surveyed for *Trochus niloticus*. Sites 11 and 14 on the western barrier reef are former trochus sanctuaries.

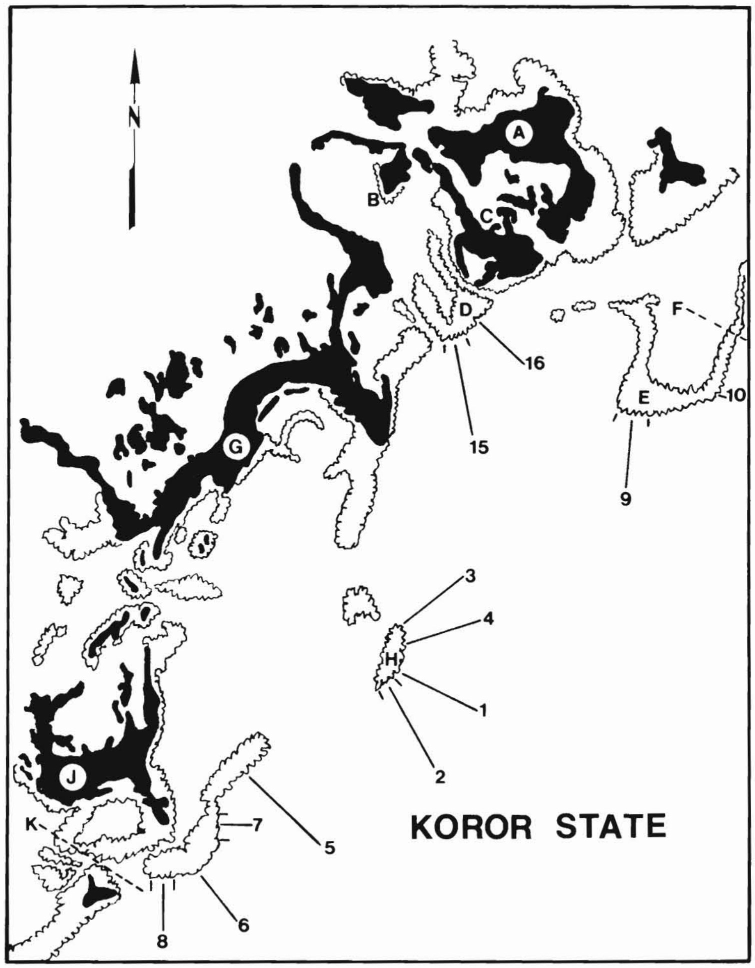

Figure 3.—Koror State eastern barrier reef complex, with numbered *Trochus niloticus* survey sites. A, Koror Island; B, Malakal Island, site of the MMDC Laboratory; C, Auluptagel Island; D, Ngederrak Reef, site of present trochus sanctuary; E, Augupelu Reef; F, Koror-Airai State boundary; G, Urukthapel Island; H, Ikedelukes Reef, site of present trochus sanctuary; J, Eil Malk Island; K, Denges passage (marks Koror-Peleliu State boundary). Sites 2, 7, 8, 9, and 15 are former trochus sanctuaries.

develop a pragmatic model that can be used for future surveys of this kind, both in Koror and elsewhere.

Methods

We surveyed 16 outer reef sites, 7 within existing trochus sanctuaries and 9 in exploited areas, generally within 2 km of the sanctuaries (Fig. 2, 3). At each site a 100 m lead core transect line was placed on the substrate (approximately parallel to the reef margin) along four depth contours at 7, 5, 3, and 1 m. These depths were chosen because they cover the ranges commonly accessible to free diving trochus fishermen. In Palau and elsewhere, most trochus are harvested between 1 and 5 m depth.

Two scuba divers carefully searched the substrate along each depth contour and recorded all *T. niloticus* within 2 m of each side of the transect line. About 400 m^2 of substrate were surveyed at each depth contour and 1,600 m^2 were covered at each of the sites shown in Figure 2. Divers used measuring boards fitted with underwater paper to record the number and size of specimens in the following categories:

1) Live *T. niloticus*,
2) dead *T. niloticus* with empty shells,
3) dead *T. niloticus* occupied by the hermit crab *Dardanus megistos*,
4) dead *T. niloticus* occupied by the crab *D. lagopodes*, and
5) live *T. pyramis*.

In addition, notes were made regarding the following habitat characteristics:

1) Depth,
2) compass orientation of reef margin (N, S, E, W, etc.),
3) degree of wave exposure,
4) bottom slope, and
5) substrate type and composition.

Data on dead *T. niloticus* shells, hermit crabs, and *T. pyramis* were collected for an ancillary study on predation and competition. The design of this study thus allows quantitative data to be collected simultaneously on a variety of species or phenomena.

The time required for searching each 100 m transect was about 15 minutes/diver, and about 2 man-hours of underwater search effort were expended at each site. The surveys were deliberately conducted during Palau's calmest months to take advantage of the lull between northeast trade winds and southwest monsoons. We doubt that transect-type trochus surveys can be conducted accurately or safely in shallow water if surf heights exceed 1 m. Nash (1981) reached a similar conclusion. Although surveys in our study were conducted on different days of the lunar month (hence at different tidal levels), the effect on accuracy of the stated depth contours is minimal since the mean tidal range in Palau is only 1 m.

Locations of the surveyed sites were determined from U.S. Defense Mapping Agency Chart No. 8841 (Palau Islands; scale 1:165,000) and from U.S. Geological Survey Maps (Republic of Palau; scale 1:10,000).

Results

Trochus niloticus abundance and distribution data at 16 Koror State sites are presented in Table 1. Densities ranged from 0 to 750 animals/hectare, with an overall mean of 119.

Table 2 compares trochus densities in sanctuary and exploited areas. Although there was high within-contour variance in both categories, sanctuary sites had significantly lower trochus densities than exploited areas at the 1 and 3 m contours. On average, sanctuary sites had only half as many trochus as exploited sites.

Figure 4 indicates the existence of a significant negative correlation between water depth and trochus density in exploited sites. Shallow sites had larger numbers of relatively small animals. As depth increased fewer trochus were found but their mean size was larger. A similar trend in size zonation has been reported for trochus populations at Guam (Smith, 1979) and elsewhere (Moorhouse, 1932; Rao, 1937); however, the depth-density correlation found in Palau has not been reported previously. In New Caledonia, maximum trochus densities are said to occur in the boulder zone of shallow reef flats (Bour and Gohin, 1982).

Despite considerable searching we found no small (<20 mm) *T. niloticus* juveniles in the subtidal contours surveyed. Young *T. niloticus* appear to settle exclusively in outer reef flat intertidal areas and migrate into deeper water as they grow (Heslinga, 1981b).

The relationship between depth and size of *T. niloticus* is evident when size-frequency histograms are plotted for subpopulations at successive depth contours (Fig. 5). Clearly, deep-water populations have higher percen-

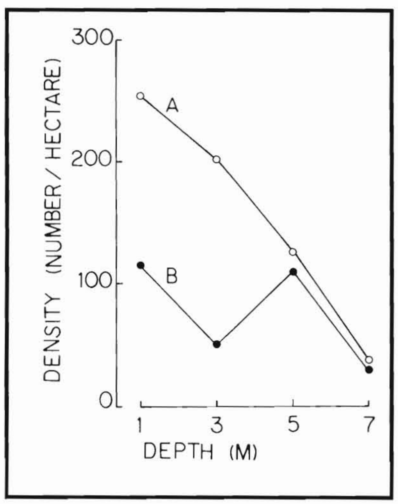

Figure 4.—Relationship between depth and mean density of *Trochus niloticus* on the seaward barrier reefs of Koror State. A significant negative correlation (r = −0.99; p < 0.01) between depth and density was found between 1 and 7 m depth in exploited area. A, exploited areas; B, sanctuaries.

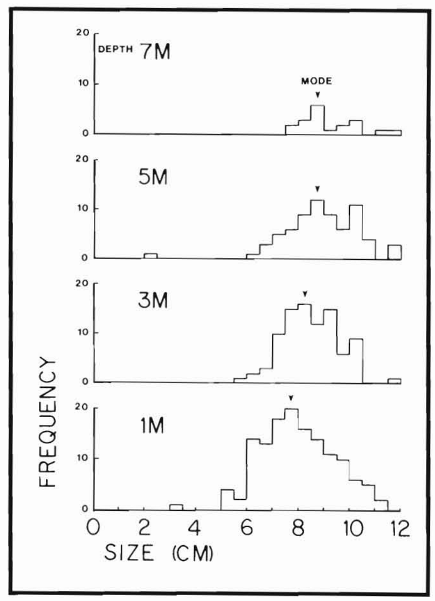

Figure 5.—Size-frequency distributions of *Trochus niloticus* at four depth contours on the seaward barrier reefs of Koror State, 1982. Data were pooled from 16 sites covering 25,600 m². Modal size (arrows) increased with depth while density decreased with depth. Sample sizes at the 7, 5, 3, and 1 m contours were 19, 70, 91, and 136, respectively.

tages of relatively large specimens. The modal size of *T. niloticus* in the 7 m and 5 m contours was 86-90 mm, and this decreased to 76-80 mm at the 1 m contour. If it is assumed that the depth-density correlation in Figure 4a is roughly linear, we can predict that trochus density would approach zero at about 8 m. This prediction agrees well with our field observations, and supports the position of McGowan (1958) that there are no "large, untapped reserves of trochus in deeper water."

In addition to being correlated with depth, trochus densities in the areas surveyed were dependent on reef orientation (Fig. 6). On individual east-coast reefs (Ngederrak, Ikedelukes, and Pelugauar) there was a general trend of decreasing density along a gradient running clockwise from northeast to south. In nearly all cases the south and southeast facing reef sections supported fewer trochus than nearby east or northeast facing sections. The south and southeast facing reef sections were calmer sites, consistently characterized by a sandier, more heterogeneous substrate than the exposed north and northeast facing sections. These latter areas were high energy zones which displayed a more consolidated substrate with broad patches of pavement, coralline algae, and low filamentous algae. Live coral cover was uniformly lower in the shallow contours of the high energy sites.

Spot checks of shallow subtidal zones on the lagoonward (west-facing) side of the surveyed reefs revealed broad sandy patches, occasional live coral heads, and a total absence of *T. niloticus*. All these

Table 1.—Commercial *Trochus niloticus* stock densities in Koror State survey areas, March-April 1982.

Site	Date surveyed	Exposure	Depth (m)	Number of trochus per quadrat	Maximum size (mm)	Mean size (mm)	Density by depth (no. per hectare)	Mean site density
1	3/18	ESE	7	6	116	101	150	
			5	7	119	106	175	
			3	6	101	92	150	
			1	2	79	64	50	131
2[1]	3/18	SE	7	2	103	96	50	
			5	9	102	86	225	
			3	2	95	87	50	
			1	6	86	76	150	119
3	3/30	NE	7	1	100	100	25	
			5	14	106	93	350	
			3	20	101	87	500	
			1	29	113	81	725	400
4	3/30	ENE	7	0			0	
			5	13	109	93	325	
			3	9	103	87	225	
			1	30	106	81	750	325
5	4/20	SE	7	0			0	
			5	1	24	24	50	
			3	20	101	80	500	
			1	15	110	85	375	231
6	4/02	SSE	7	1	82	82	25	
			5	3	77	73	75	
			3	2	74	71	50	
			1	7	82	64	175	81
7[1]	4/06	ENE	7	4	103	92	100	
			5	15	100	86	375	
			3	7	103	80	175	
			1	15	100	83	375	256
8[1]	4/06	S	7	1	78	78	25	
			5	0			0	
			3	1	72	72	25	
			1	9	86	71	225	69
9[1]	4/08	S	7	1	85	85	25	
			5	4	91	88	100	
			3	2	83	80	50	
			1	0			0	44
10	4/08	E	7	2	89	85	50	
			5	1	101	101	25	
			3	0			0	
			1	0			0	19
11[1]	4/13	W	7	0			0	
			5	0			0	
			3	0			0	
			1	2	82	78	50	13
12	4/13	SSW	7	1	86	86	25	
			5	3	95	82	75	
			3	1	101	101	25	
			1	0			0	312
13	4/19	WNW	7	0			0	
			5	0			0	
			3	0			0	
			1	0			0	0
14[1]	4/19	WNW	7	0			0	
			5	0			0	
			3	0			0	
			1	0			0	0
15[1]	4/22	SSE	7	1	86	86	25	
			5	3	95	82	75	
			3	1	101	101	25	
			1	0			0	31
16	4/22	SE	7	0			0	
			5	2	103	89	50	
			3	14	102	88	350	
			1	8	98	83	200	150

[1]Former sanctuary site.

Table 2.—Comparison of commercial *Trochus niloticus* densities in sanctuaries and exploited areas, Koror State, 1982. Densities are expressed in mean number per hectare. Exploited areas had significantly higher (T-test of means) trochus densities than sanctuaries at the 1 and 3 m contours. Sites where no trochus were found were excluded from the analysis.

Depth contour (m)	Density		Significant difference?
	Sanctuary	Exploited	
1	200	379	Yes ($p < 0.1$)
3	65	257	Yes ($p < 0.05$)
5	255	153	No
7	45	55	No

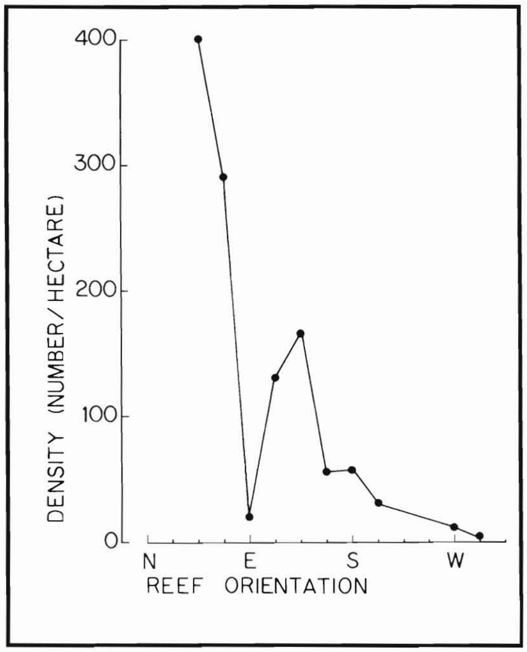

Figure 6.—Relationship between reef orientation and mean density of *Trochus niloticus* at surveyed sites in Koror State, 1982. Density was positively correlated with degree of exposure to surf, and generally decline along a NE, E, S, W gradient.

observations are consistent with the generalization that, in Palau, this species is virtually restricted to hard substrates on seaward reefs. McGowan (1958), however, lists examples of other islands in Micronesia where substantial trochus populations were found on lagoonward reef slopes.

Discussion

Our survey results provide a quantitative picture of commercial trochus populations inside and outside marine sanctuaries that have existed for over 20 years in Koror State. Three questions must now be addressed.

1) Was the sanctuary system working as originally intended?
2) If not, why?
3) What constitutes an appropriate habitat for a trochus sanctuary?

Koror State survey data indicate that, on average, the seven surveyed sanctuary sites had only half as many trochus as nearby exploited areas. Had the system been working as originally planned, higher trochus densities should have been found inside the sanctuaries. Thus, the sanctuary system was only marginally effective at the time of the survey.

The two sanctuaries located on Koror's western barrier reef (sites 11 and 14) had such low numbers of trochus that they were essentially useless. These sites appear to have been chosen arbitrarily. Because most of Koror's western barrier reef drops off steeply, minimal intertidal and shallow subtidal habitats are available for trochus. Moreover, the outer reef flats are generally submerged at low tide and lack the boulder and rubble-strewn intertidal zone that seems favorable to the recruitment of juvenile trochus (Heslinga, 1981b). Our census data support the position that Koror's west coast barrier reef is marginal-to-poor trochus habitat. Not surprisingly, this area is seldom visited by trochus harvesters.

Of the five remaining trochus sanctuaries in Koror State, four (sites 2, 8, 9, and 15) were located on the south or southeast facing sections of their respective reefs. As noted, these were relatively calm sites with sand and live coral dominating the surveyed depth contours. These substrate types offer numerous hazards to *T. niloticus* of all ages and are probably actively avoided. Settling larvae and post-larvae can be consumed by live corals or buried under shifting sand. Juvenile and adult trochus probably avoid sand because it inhibits locomotion and adhesion of the foot. Locomotion across live coral is undesirable because it would expose the foot to stinging nematocysts. We have never observed *T. niloticus* crawling on or adhering to live coral in nature. Perhaps most important, live coral and loose sand do not promote growth of the low filamentous algal species which form a principal part of the *T. niloticus* diet.

Based on this line of reasoning, we concluded that four of the five trochus sanctuaries on Koror's east coast had been placed in marginal or poor habitats. Only one of the east-coast sanctuaries (site 7), located on an east-northeast facing reef, had a suitable substrate composition (dominated by pavement and coralline algae) and a high density of trochus relative to nearby areas.

Of the areas surveyed, the one with the most favorable conditions for *T. niloticus* was Ikedelukes, an exposed barrier reef segment about 5 km south of the Malakal Lighthouse (Fig. 7). Ikedelukes embodies a number of physical and biotic characteristics which we believe are ideal for trochus sanctuaries. These include an unobstructed exposure to surf generated by northeast trades, a gently sloping bottom, a wide reef flat that is exposed at spring low tides, a subtidal substrate that is predominantly pavement (especially in shallow contours), and an abundance of coralline algae and low filamentous algae at 1-3 m.

Ikedelukes supports an immense number of grazing herbivorous fishes, with acanthurids and scarcids being particularly abundant. The blueline surgeonfish, *Acanthurus lineatus*, is especially conspicuous at Ikedelukes and may be a useful "indicator" organism for superior *T. niloticus* habitats. Similarly, the presence of other herbivorous archaeogastropods at Ikedelukes, including *T. pyramis*, *T. incrassatus*, *T. maculatus*, and *Turbo argyrostoma*, implies that this reef is particularly favorable for grazers.

Ikedelukes is far enough from the commercial port of Palau (35 minutes by speedboat) to make pollution a minimal concern; however, the reef is close enough to allow surveillance and experimental work. Most important, Ikedelukes had high numbers of mature *Trochus niloticus* relative to other nearby sites. All of these considerations figured in our eventual decision to recommend Ikedelukes as a permanent trochus sanctuary for Koror State.

We emphasize that trochus sanctuaries must be placed near enough to district centers to allow periodic surveillance. In the case of Koror State's western barrier reef sanctuaries, it is unlikely that they were ever visited by conservation personnel simply because of their great distance from Koror Island. Similarly, the number of reefs designated as sanctuaries should not place an excessive burden on the surveillance capabilities of local authorities. In retrospect, this was certainly the case in the Koror State system.

Ecologically and economically, the optimum number and size of trochus sanctuaries for a given locale are unknown and open to debate (Bradbury and Reichelt, 1981). Thus, in many respects the sanctuary concept must still be regarded as an experimental management policy. A scientific approach to the questions involved is highly desirable but would undoubtedly demand far more time and expense than are likely to be available. In any event, it is clear that in most trochus producing countries the amount of reef area devoted to preservation is likely to depend more on political and economic realities than on the persuasiveness of theoretical arguments. Until more is known about coral reef ecology and about reef ecosystem management, the best that can be achieved is some form of compromise between exploitation and conservation, based on as much quantitative information as possible and an appreciation for local conditions and customs.

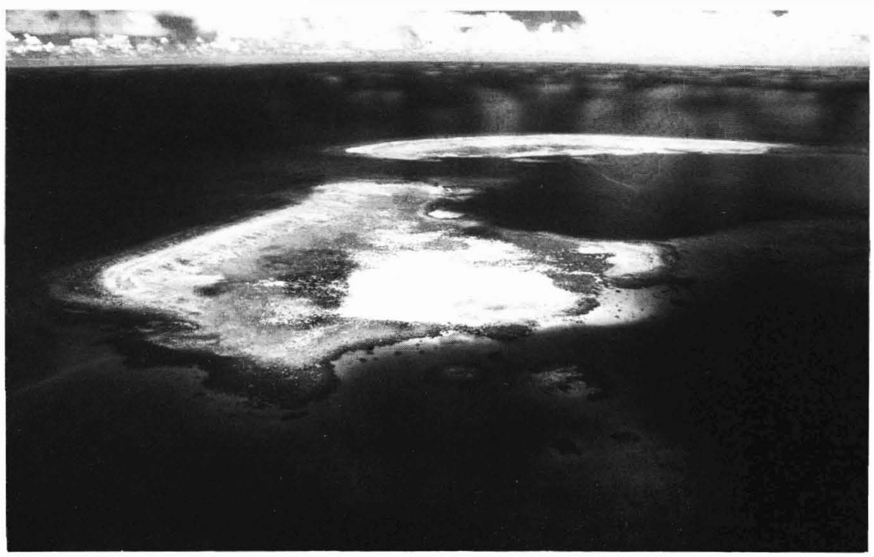

Figure 7.—Aerial view of Ikedelukes Reef in Koror State, presently a sanctuary for commercial trochus. Photograph courtesy of and copyright by Douglas Faulkner, N.Y.

Following the completion of the trochus surveys in Koror State, we recommended to government officials that the trochus sanctuaries be reduced and consolidated into two moderately sized, centrally located reefs near enough to Koror to be visited frequently by conservation personnel. Ikedelukes Reef and Ngederrak Reef (Fig. 7) were selected as sanctuaries because they fulfilled the necessary physical, biotic, and geographic requirements reasonably well.

We also recommended that whole reefs (from channel to channel) be designated as sanctuaries because this would eliminate the time-consuming annual task of placing markers on the reefs to delineate sanctuaries. It seems practical, where possible, to treat whole reefs rather than portions of reefs as management units.

The proposed revisions to the Koror State trochus sanctuary system were approved in May 1982 by the Mayor and Chief, Ibedul Yutaka Gibbons (Heslinga, 1982). The harvest season opened the following month and lasted 4 weeks. The new sanctuary regulations were broadcast over local radio in the weeks before harvesting began. During the season the new trochus sanctuaries were patrolled regularly by Marine Resources Division personnel, including the authors. A few sporadic incidents of sanctuary poaching were observed; the fishermen involved claimed ignorance of the radio broadcasts and willingly moved out of the sanctuaries when informed of the new regulations. In 1983 Koror State officials declared a moratorium on trochus harvesting, and no violations were observed during routine checks of the sanctuary reefs. We believe that future trochus poaching incidents in Koror State will be negligible if surveillance is maintained during the harvest season.

The need to establish coral reef sanctuaries and other conservation measures in the nations of the tropical Pacific is widely recognized (Johannes, 1978, 1982; Salvat, 1981; Stoddart, 1981; Wells, 1981b; Kelleher and Kenchington, 1982), especially in areas where traditional forms of reef tenure and resource protection have been eroded by urbanization and the effects of Western contact. Our study is instructive because it illustrates a case in which quantitative data were used successfully to lobby for the improvement of a coral reef management program. We assembled evidence showing that a 20-year-old trochus sanctuary system would likely be improved by some simple modifications, specifically, consolidation and relocation to superior habitats. Local Marine Resources Division personnel were trained to evaluate the problem and subsequently participated in proposing a solution. The assistance and approval of the Koror State Mayor and Chief were actively sought and proved instrumental in achieving an acceptable modification of policy. It is significant, too, that baseline data were established and practical methods developed to serve as a model for future comparative analyses.

Acknowledgments

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